MISSION ASSURANCE ANALYSIS OF THEATER BALLISTIC MISSILE DEFENSE SYSTEMS

GRADUATE RESEARCH PROJECT

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Abstract

In today's budget-constrained environment with aging equipment and rapid technology turnover, the commander's requirement to prioritize and justify funding requests has essentially become an exercise in mission assurance. This study addresses the Theater Ballistic Missile Defense Systems (TBMDS) mission assurance problem generated from the complexity of the political, organizational and physical/architectural environments.

The Mission-Oriented Success Analysis and Improvement Criteria (MOSAIC) management approach provides commanders a framework for mission assurance of TBMDS. This study specifically incorporates a discrete event simulation analysis and the Mission Assurance Analysis Protocol (MAAP) to identify the most effective improvement areas under the MOSAIC approach.

At a high level of abstraction, analysis from a discrete event simulation of the TBMDS prioritized the component reliability from the most to least impactful as shooter/interceptor, C2 facility, Radar and Communication. The MAAP expanded success profiles simultaneously address multiple environmental factors, including reliability, for each key objective needed for the mission. At an equally high level of abstraction, these profiles identified that the key objective to strengthen US security relations of the TBMDS can be achieved successfully and three key objectives, negate effectiveness of Theater Ballistic Missile (TBM), negate likelihood of TBM, and protect/defend forces/population centers, had significant mission assurance gaps. With improvement areas and mission assurance gaps identified, commanders are equipped

with the required information for funding requests and confidence in the success of their mission.

This graduate research project is dedicated to my family.

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Susan R. Olsen

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List of Abbreviations

ACC	Acquisition Community Connection
AFIT	Air Force Institute of Technology
AN/TPY-2	Army Navy/Transportable Radar Surveillance
BMC3	Battle Management Command, Control and Communications
BM/C3	Battle Management Command, Control and Communications
BMC3I	Battle Management Command, Control, Communications and Intelligence
BM/C3I	Battle Management Command, Control, Communications and Intelligence
BMD	Ballistic Missile Defense
BMDR	Ballistic Missile Defense Review
BMDS	Ballistic Missile Defense Systems
C2	Command and Control
C2BMC	Command and Control, Battle Management Communications
CI	Confidence Interval
CJCS	Chairman Joint Chiefs of Staff
EPAA	European Phased Adaptive Approach
DoD	Department of Defense
I/O	Input/Output
JTMP	Joint Theater Missile Programs
MAAP	Mission Assurance Analysis Protocol
MDA	Missile Defense Agency
MEF	Mission Essential Functions

MOA	Mission Operations Assurance
MOSAIC	Mission-Oriented Success Analysis and Improvement Criteria
MTBF	Mean Time Between Failures
MTTR	Mean Time To Repair
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
NIST	National Institute of Standards and Technology
RDECOM	Research, Development and Engineering Command
SECDEF	Secretary of Defense
SEI	Software Engineering Institute
SME	Subject Matter Expert
SM-2	Standard Missile Block 2
SM-3	Standard Missile Block 3
TBMDS	Theater Ballistic Missile Defense System
TBMD	Theater Ballistic Missile Defense
TMD	Theater Missile Defense
US	United States
USEUCOM	United States European Command

MISSION ASSURANCE ANALYSIS OF THEATER BALLISTIC MISSILE DEFENSE SYSTEMS

Chapter 1. Introduction

1.1. Background

Commanders in today's budget constrained US military have the opportunity to improve mission enabling processes and systems within their command by eliminating unnecessary redundancies and non-value added processes (Chavez, 2011). At the same time, the available military budget is dispersed under a prioritized requirement driven process (ACC, 2011). The commander's decision to improve, remove, or add a process/system essentially becomes an exercise in mission assurance. In addition, technology is continually changing the battlespace to support the warfighter in their escalating-capabilities race for superiority. Therefore, commanders at all levels have an ever present need to efficiently maintain mission assurance of their enabling processes and systems in the midst of this dynamic environment.

Historically, the major portion of any mission assurance program was risk management. Traditional risk management approaches attempted to foresee and mitigate issues that could hinder mission success with infinite levels of detail. "The traditional risk management process is the sequential application of five discrete action steps: identify, measure, select, implement and monitor" (Burlando, 1990). Not only was this process time consuming, but was also typically accomplished by a few isolated technicians. Commanders today cannot afford to manage mission success in such a fashion. "Mission success in complex settings demands a collaborative management approach that effectively coordinates task execution and decision-making activities among all participating groups" (Alberts et. al., 2007).

1.2. Motivation

In 2010, US European Command desired to better understand the limitations involved with completing a war plan that included system of systems surrounded by dynamic political, organizational and physical/architectural environments. This study is a part of a larger Air Force Institute of Technology (AFIT) effort and uses a Theater Ballistic Missile Defense System (TBMDS) case study to propose a mission assurance process able to handle the complexity of a system of systems and explore the possibility that a commander can manage system resources/processes using mission assurance in pursuit of operational mission success.

Though research on mission assurance is not new, previous research has mainly focused on program/project/process mission assurance or cyberspace mission assurance. Many of the approaches developed within these areas leverage traditional risk management in establishing mission assurance. However, with all the mission assurance tenets of reliability, quality assurance, force protection, system safety, etc., the central focus of mission assurance should be mission success (Bryant, 2011; DoDb, 2010) as opposed to hazard risk aversion.

The inherent joint and coalition operational complexities of a TBMDS make it a great research candidate for developing a mission assurance approach. Additionally, in the current round of downsizing and budget cuts, commanders are even more reliant on mission assurance to make sound budget decisions as the obvious mission areas have already been optimized. In the midst of all the politics and missile defense restructuring plans, military operations are still being conducted, and commanders at all levels still require mission assurance of the systems they employ from day to day. Under the current Administration's strategy, the United States is pursuing "a phased adaptive approach to missile defense within each region that is tailored to the threats and circumstances unique to that region" (DoDa, 2010). Therefore, mission assurance of a region's Theater Ballistic Missile Defense (TBMD) will necessarily rely on the input of the region's commanders. Furthermore, due to the nature of DoD acquisitions, systems and the communication networks they use are generally designed/managed separately. This often makes it difficult for commanders to prioritize funding requirements for a capability when trying to improve, maintain, or streamline a particular mission area.

1.3. Research Objectives and Structure

From the TBMDS perspective, prior research has focused mainly on the architecting of system coverage designs versus providing commanders' mission assurance of their TBMD systems. This research effort attempts to look at U.S. European Command's (USEUCOM) TBMD system to help the commanders identify risk and opportunity that can have an impact on the ability to achieve the Department of Defense's (DoD's) objective to protect forward-deployed and expeditionary elements of the U.S. armed forces as well as friends and allies of the United States from a given region's ballistic missile threats (Alberts, et al., 2008; SECDEF, 1995).

This study was conducted using the Software Engineering Institute (SEI) Mission-Oriented Success Analysis and Improvement Criteria (MOSAIC)[1] approach to establish confidence that the key objectives of the TBMDS are achieved successfully or area(s) are identified that require attention in order to attain that confidence/ provide mission assurance (Alberts et. al., 2007). The MOSAIC approach employed two separate but supporting assessments. The first assessment was a discrete event simulation analysis using Rockwell's ARENA simulation tool. The ARENA simulation model helped prioritize improvement areas of a TBMDS by looking at the system components to determine which area(s) or component(s) would contribute most to increasing mission success (Arena, 2007). This tool provided statistically significant data and quantified improvement projections to support a TBMDS prioritized funding request. The second assessment of this study used the Mission Assurance Analysis Protocol (MAAP)[2] to simultaneously address multiple environmental factors, including reliability, for each key objective needed for mission assurance (Alberts et.al., 2008).

With improvement areas and mission assurance gaps identified, commanders are provided with the required information for funding requests and confidence in the success of their mission.

1.4. Research Scope

This effort will leverage representative reliability data to demonstrate how mission assurance for a TBMDS could be assessed. The MAAP that will be executed is

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[1] MOSAIC was developed by the Software Engineering Institute (SEI) at Carnegie Mellon University, Copyright 2007. Details on MOSAIC are provided in Chapter 2.
[2] MAAP was developed by the Software Engineering Institute (SEI) at Carnegie Mellon University, Copyright 2008. Details on MAAP are provided in Chapter 2.

also illustrative as a full MAAP assessment with extensive manpower, full support from process owners and enterprise-wide alignment of key objectives are beyond the scope of this research effort. As such, only select top-level key objectives were included to demonstrate the MAAP assessment flow and capabilities.

Chapter 2. Literature Review

The larger body of previous research has focused on the architecture of the TBMDS which is essential to understand before tackling any analysis of this system and the concept of mission assurance. Even though many of the specific mission assurance efforts do not adequately address system complexity or are not operationally relevant, they are important to recognizing the necessary diversity of mission assurance approaches. This chapter discusses TBMDS and a commander's inherent need for mission assurance. It then addresses the challenges commanders face trying to achieve mission assurance and the current areas of mission assurance research. After a thorough review of mission assurance, the chapter will conclude with a mission assurance approach for TBMDS.

2.1. Theater Missile Defense Program Concepts and Current State

The Theater Missile Defense (TMD) programs can be considered a system of systems or family of systems program. Multiple sources speak to these programs and their composition. Army Field Manual (FM) 3-01 describes a typical TMD architecture as a combination of shared and dedicated components that consist of long range sensor(s), an In-Flight Interceptor Communications System and a battle management, command and control and communications (C^3) network (AFM 3-01, 2009). The long range sensor(s) provide early warning and surveillance of ballistic missile launch while the In-Flight Interceptor destroys the missile in flight (from boost phase to descent phase by offensive or defensive means). The battle management C^3 network supports sensor management, data processing and dissemination, and command, control and communications.

The TMD programs directly support many separate programs efficiently by accomplishing tasks that otherwise would have to be achieved by separate programs. The Command and Control, Battle Management Communications (C2BMC) provides interoperability that is essential for joint TMD operations. The Missile Defense Agency (MDA) purposely established an architecture that all the Services can build upon that includes improving early warning and dissemination, ensuring communications interoperability, and upgrading command and control centers. These capabilities are absolutely critical to the success of the overall U.S. Missile Defense system. They are often referred to as the glue that holds the architecture together and ensures that the whole is greater than the sum of its parts (JTMP, 2004).

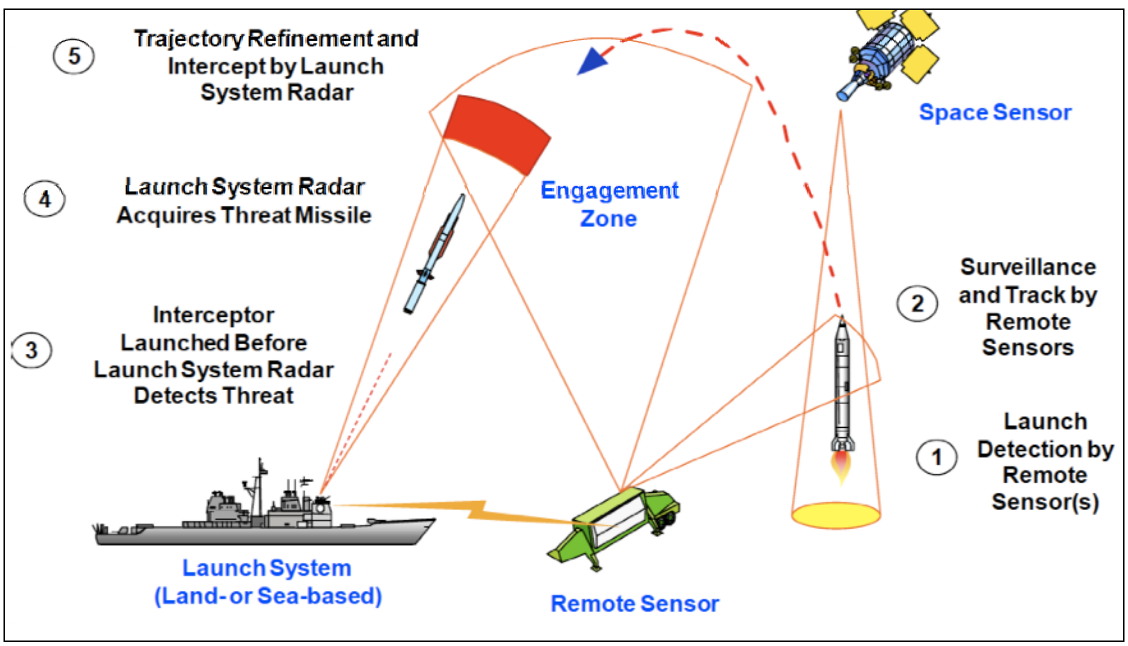

Figure 1. Conceptual TBMDS (DoDa, 2010)

Figure 1 depicts the basic engagement sequence without the separate C2BMC interaction and a futurist launch on remote concept. The current TBMDS response is initiated when remote sensor(s) detect a ballistic missile launch as shown as step number 1 in Figure 1. Remote sensor(s) relay surveillance and track information to the C2BMC which tracks the ballistic missile threat with the theater's own remote sensor. The tracking and surveillance by these remote sensors is depicted by step 2 in Figure 1. The C2BMC determines the intent of the missile, identifies a required course of action, and sends an engagement order to the launch system for hostile missile threats. Current TBMDS require that the launch system's own radar be able to identify the threat missile before launch therefore reversing the order of steps 3 and 4 in Figure 1 (DoDa, 2010). Finally, in a successful mission scenario, the launch system radar refines the trajectory and successfully intercepts the ballistic missile as shown in step 5 in Figure 1.

The engagement sequence described above conveys the distinct functions of the various components of the TBMDS. TBMDS distinct functions have driven research and development to be very component specific. As such a system overview will briefly outline the individual components beginning with the C2BMC also referred to as BMC3, BMC3I, BM/C3 and BM/C3I over the years. The C2BMC program has the responsibility to integrate the other BMDS components. The C2BMC in and of itself is a conglomeration of capabilities. The command and control element covers the functionalities that support planning and situational awareness. The battle management element is responsible for supporting the combatant commander in making the decision to commit a weapon system, while the communications element is responsible for providing the communications capabilities for the BMDS (Miller, 2008). The C2BMC strives to “enable coordinated, real-time decision-making by war-fighters and leaders across the globe, up to and including the secretary of defense and the president of the United States” (Jay, 2009). The C2BMC’s specific mission is to “provide a combatant command decision aid to integrate and globally synchronize missile defense systems and operations.” To fulfill this mission, the C2BMC provides five main functions: 1) the communications links and connectivity between ballistic missile defense components, 2) a battle management function to allow a shoot/look/shoot approach that maximizes BMDS effectiveness, 3) control of the BMDS radars, 4) real-time awareness of the battlespace to include interoperability with NATO, and 5) advanced battle planning capability that enables warfighters to place BMDS assets in optimal locations in anticipation of an upcoming battle (Jay, 2009).

On September 17, 2009 President Obama announced the U.S. decision to adopt a new approach to ballistic missile defense in Europe called the European Phased Adaptive Approach (EPAA). The EPAA calls for “operating BMD-capable Aegis ships in European waters to defend Europe from potential ballistic missile attacks from countries such as Iran” (O’Rourke, 2010). In support of the EPAA, USEUCOM’s C2BMC capabilities were recently improved by the “activation of C2BMC servers, providing track forwarding to in-theater BMD Aegis ships, situational awareness of the regional BMD mission, and control for the forward-based AN/TPY-2 radar in support of the Defense of Israel” (MDA, 2011). In addition, in March 2011, the United States announced the deployment of the USS Monterey to the Mediterranean to begin a sustained deployment of Aegis BMD-capable ships in support of the EPAA (EPAA and NATO Missile Defense, May 2011). The Aegis BMD-capable ships provide interceptor capability in the European theater with SM-2 and SM-3 missiles (O'Rourke, 2010).

The last TBMDS component, the long range sensor(s), have seen significant improvement since the inception of the AN/TPY-2 X-band radars providing detection and tracking of ballistic missiles at very long ranges. The direct radar-CSBMC link adds valuable seconds to the decision making process between missile launch and interception (Graves, 2008 and 94th AAMDC, 2009). These improvements provide greater flexibility and mission assurance of USEUCOM's TBMDS.

2.2. Concept of Mission Assurance

DoDD 3020.40 defines mission assurance as:

> *A process to ensure that assigned tasks or duties can be performed in accordance with the intended purpose or plan. It is a summation of the activities and measures taken to ensure that required capabilities and all supporting infrastructures are available to the Department of Defense to carry out the National Military Strategy. It links numerous risk management program activities and security-related functions, such as force protection; antiterrorism; critical infrastructure protection; IA; continuity of operations; chemical, biological, radiological, nuclear, and high explosive defense; readiness; and installation preparedness to create the synergy required for the Department of Defense to mobilize, deploy, support, and sustain military operations throughout the continuum of operations.* (DoD,2010)

Mission assurance by this definition is a must for any commander (Abercrombie et. al., 2010; Evans, 2010; Hale, 2010; Hale, et.al., 2010). However, mission assurance management shares similar management considerations with risk management and information assurance like, scope, definition flexibility, rapid technology change rate and subjectivity (Grimaila et. al., 2010). First, scoping/bounding the mission to the appropriate level is an art unto itself. Scoping the mission too large means the commander does not have the authority to control/influence all the components required to fulfill the mission. Scoping the mission too small, generally leads to micromanaging a subordinate’s mission area and neglect of other mission areas (NIST, 2010). Secondly, the term “mission assurance” is very flexible. It has and can be used throughout the life cycle of a system (Guarro, 2007) or to ensure any objective is met. Air Force Doctrine Document 3-12 describes mission assurance as “measures required to accomplish essential objectives of missions in a contested environment” (Department of the Air Force, 2010). In this research paper however, mission assurance will refer to the operational part of the system’s lifecycle as it relates to the mission objectives. This will ensure once again that the commander has the authority to control/influence the components required to fulfill the mission. Thirdly, with the current rate of change in technology, the suggested rapid refresh rates and interoperability improvement initiatives, the components required to fulfill the mission are changing constantly. Thus analysis done to support mission assurance could effectively be obsolete the moment it is collected (Isaacs, 1999). Finally, mission assurance is inherently subjective (Weaver, 2005). Therefore, mission assurance is dependent upon the individual in charge. Two different individuals may have differing opinions on the mission assurance of the exact same system. These aspects of mission assurance and more, make research on mission assurance relatively area/system specific.

The current areas of research in mission assurance tend to fall in four groups cyberspace mission assurance, program/project mission assurance which tends to be acquisition/business focused, NASA’s Mission Operational Assurance (MOA), and process mission assurance. The rest of this section will briefly touch on these research areas and determine the approach that fits the needs of a TBMDS commander’s mission assurance requirements best.

Air Force Doctrine Document 3-12, Cyberspace Operations, reflects that “mission assurance entails prioritizing Mission Essential Functions (MEFs), mapping mission dependence on cyberspace, identifying vulnerabilities, and mitigating risk of known vulnerabilities” (Department of the Air Force, 2011). In their Journal of Strategic Security article, “The Science of Mission Assurance,” Jabbour and Muccio use the same terms to describe a cyberspace mission assurance methodology: prioritization, mission mapping, vulnerability assessment and mitigation (Jabbour and Muccio, 2011). These approaches have essentially leveraged the traditional risk management steps (identify, measure, select, implement and monitor) on a subset of system functions effectively watering down mission assurance to merely avoiding negative consequences to MEFs (Burlando, 1990; Grimaila et. al., 2010).

Program/project mission assurance research addresses mission assurance from a systems engineering perspective and breaks mission assurance into six core processes; requirements analysis and validation, design assurance, manufacturing assurance, integration, testing, and evaluation, operational readiness assurance, and mission assurance reviews and audits (Guarro, 2007). Though program mission assurance is essential for the acquisition of major engineering endeavors, analyzing fielded operational systems require a different perspective on mission assurance.

The third area of current mission assurance research focused specifically on NASA’s Mission Operations Assurance (MOA). NASA coined the acronym MOA to distinguish between their approaches to program mission assurance and assurance of operational mission success. They laid out four MOA program requirements:

1. MOA shall independently assess project risks throughout mission operations.
2. MOA shall independently assess the project's operational readiness to support nominal and contingency mission scenarios.
3. MOA shall implement the project's problem/failure reporting system to comply with Jet Propulsion Laboratory's Anomaly Resolution Standard.
4. MOA shall provide training on problem reporting for the flight team. (Bryant, 2011)

This approach once again focuses on traditional risk management techniques to merely avoid negative consequences.

The last area of research covered in this chapter focuses on the Software Engineering Institute (SEI) Mission-Oriented Success Analysis and Improvement Criteria (MOSAIC) approach to process mission assurance. MOSAIC entails "a suite of advanced, risk-based analysis methods for assessing complex, distributed programs, processes, and information-technology systems" (Alberts et. al., 2007). Unlike traditional risk management approaches, MOSAIC uses outcome-based risk management, which assumes an aggregate view of risk that forecasts the most likely outcome from a range of possibilities and attempts to maintain the overall level of risk within acceptable limits. With the MOSAIC management paradigm shown in Figure 2, commanders can establish and maintain confidence in success at any place in the life cycle and help provide assurance at the mission, system, and program levels.

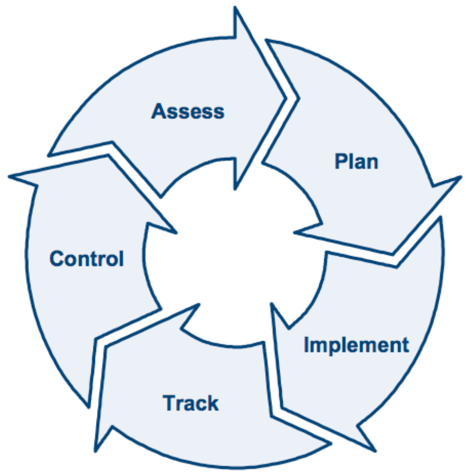

Figure 2. MOSAIC Management Paradigm (Alberts et. al., 2008)

This methodology prescribes a mission-focused approach, which facilitates consideration of complex environmental interactions. The SEI MOSAIC approach "initially focused on managing success in projects, programs, and operational processes" (Alberts et. al., 2007). This research paper will attempt to expand this methodology to the mission assurance of the TBMD system of systems.

2.3. MOSAIC for TBMDS

Review of TBMDS and mission assurance studies, support the use of MOSAIC as an efficient mission assurance process for an operational system of systems in dynamic and complex environments. MOSAIC was developed as a modular design to allow flexibility in mission assurance analysis to reflect the unique nature of the organization and environment. SEI MOSAIC is comprised of a "flexible set of methods that can be used to solve a variety of analysis problems" (Alberts et. al., 2007). It uses protocols, techniques and supporting artifacts to describe the analysis methods. The protocol defines the basic framework for conducting the analysis and lays out the sequence of activities to be preformed. The techniques describe any methods that can be used to perform the activities and the supporting artifacts are any charts, templates, etc. used in the process. Each SEI MOSAIC analysis method and associated protocols, techniques and supporting artifacts are tailored to the specific situation. Mission assurance analysis for the TBMDS will use the SEI Mission Assurance Analysis Protocol and a discrete-event simulation protocol based on the simulation study steps from a Discrete-Event System Simulation (Banks, et al., 2010).

2.3.1. SEI MAAP

MAAP expands risk-analysis to include use of an operational model to determine how potential events will affect the current value of the potential for success and an uncertainty range to represent the educated guesswork required in any risk-analysis. The assistance of the operation model provides commanders a basis for event analysis and consequence generation, while the uncertainty range represents a stochastic nature of reality. In addition, MAAP includes a sensitivity analysis for an event's effect on key process objectives. Since mission assurance is based on the commander's ability to have confidence in the process, these expansions become a multi-dimensional risk analysis in which the commander can have confidence (Alberts et.al., 2008).

MAAP is a three phase process: Phase 1, Preparing for the Assessment, Phase 2, Conducting the Assessment and Phase 3, Post Assessment Activities. However, the core assessment activities are preformed in phase 2, which typically involves a team of experts developing a detailed, descriptive operational model of the process being assessed. Additional activities include establishing key process objectives, activities, activity sequences and activity products. Then using the operational model the team developed, basic success profiles are created for each key objective as shown in Figure 3.

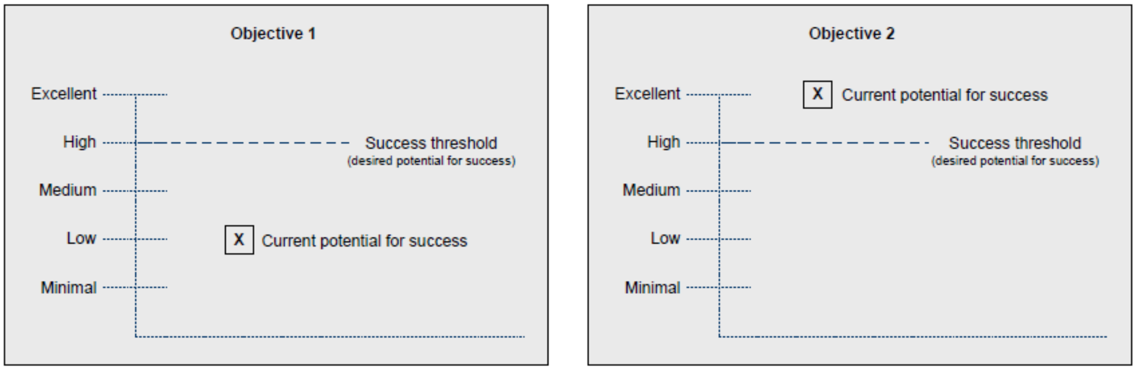

Figure 3. Basic Success Profiles (Alberts, et. al., 2008)

These represent the current probability or likelihood that the desired outcome will be achieved or exceeded. Then a causal analysis of the current state of each key objective is performed by determining the conditions and circumstances that either positively or negatively affect the execution of the distributed process. Next the uncertainty ranges are developed for each key objective based on the best- and worst-case scenarios and underlying rationale/inherent uncertainty in the distributed process as shown in Figure 4.

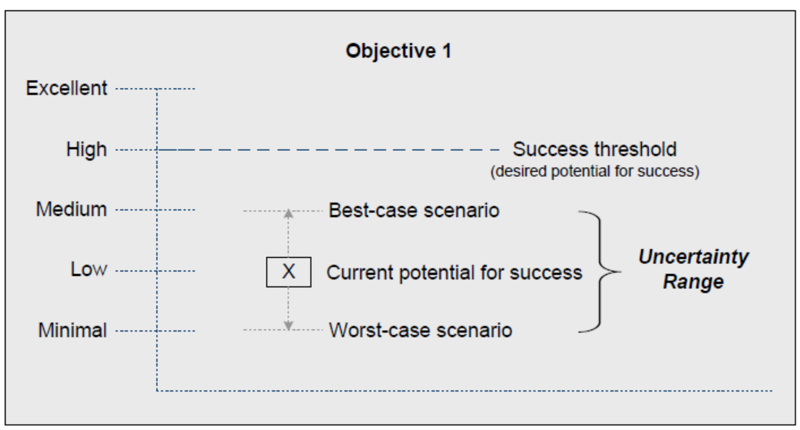

Figure 4. Success Profile with Uncertainty Range (Alberts, et. al., 2008)

Then key objective event sensitivity and causal analysis is done by the team to recognize the conditions and circumstances that drive the potential for success given the event's occurrence as shown in Figure 5.

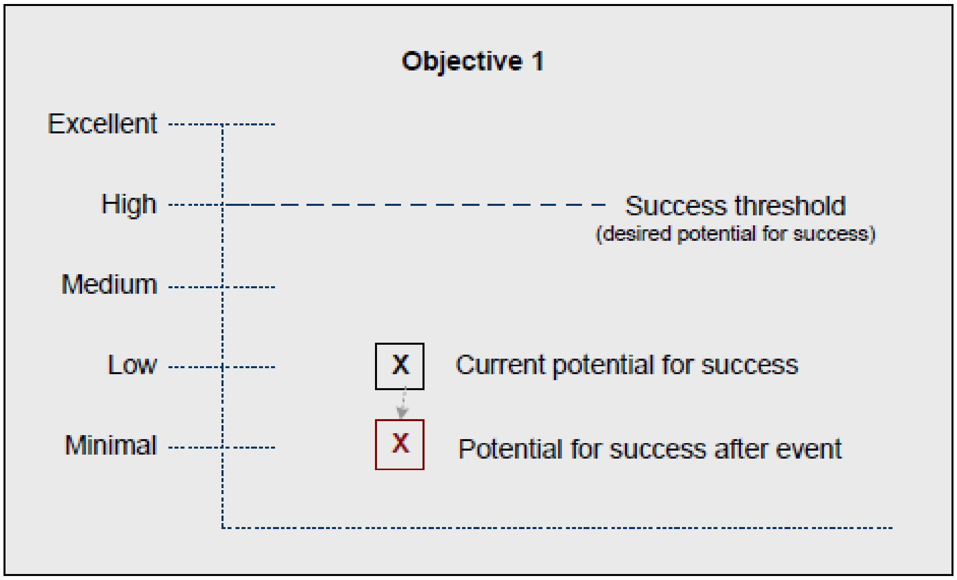

Figure 5. Success Profile with Event Sensitivity (Alberts, et. al., 2008)

Finally, an expanded success profile as seen in Figure 6 is developed from the information attained for each key objective (Alberts, et al., 2008).

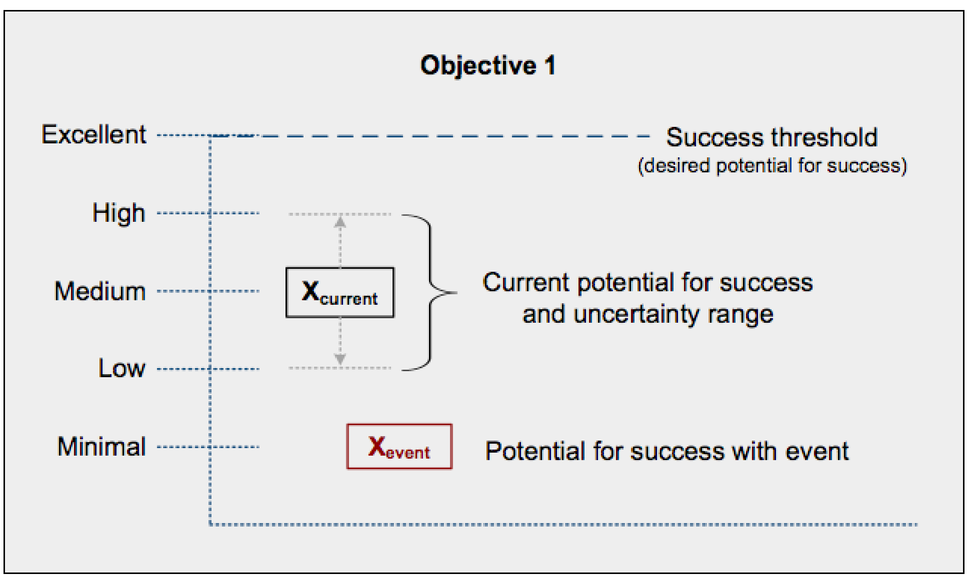

Figure 6. Expanded Success Profile (Alberts, et. al., 2008)

The individual expanded success profiles succinctly portray whether gaps or competencies exist between the desired potential for success of the objective and the team's current assessment of the objective's potential for success. Using the operational model during mission/event analysis improves the predictions of a distributed mission's potential for success over traditional risk-analysis's approach of using tacit understanding and event consequence guesswork. The comprehensive set of expanded success profiles provide insight into the issues affecting the success potential of the process and a foundation for creating detailed improvement strategies/plans or a convincing argument for confidence in mission success (Alberts, et al., 2008). Now that a MAAP overview is complete, a mechanism to support and understand the physical architecture facets included in the expanded success profiles is needed. A discrete-event simulation fulfills this need.

2.3.2. Discrete-Event Simulation

In order to ensure a thorough and sound study was conducted, the simulation study steps from a *Discrete-Event System Simulation* by Jerry Banks et. al. recommends the following protocol:

> Step 1: Problem Formulation. Establishes a statement of the problem to be addressed and ensures all parties understand the problem being analyzed and agree with the formulation of the problem statement.
>
> Step 2: Setting of Objective and Overall Project Plan. Identifies the questions to be answered by simulation and ensures that simulation is the appropriate method.
>
> Step 3: Model Conceptualization. The essential features of the problem are abstracted out and basic assumptions used to characterize the system are modified until a useful approximation results.
>
> Step 4: Data Collection. The compilation of all the input data required to drive the model.
>
> Step 5: Model Translation. Requires the conceptual model to be entered into a computational or computer-recognizable format.

Step 6: Verification. Ensures that the simulation is performing properly.

Step 7: Validation. Compares the model to actual system behavior.

Step 8: Experimental Design. Determines any alternatives to be analyzed with respect to any factor levels to include replications, run time, etc.

Step 9: Production Runs and Analysis. Estimate the system's measures of performance for the model being simulated.

The rest of this research paper is devoted to analyzing the TBMDS with the MOSAIC management approach and the synergies gained by incorporating a discrete event simulation and the MAAP assessment to provide mission assurance of a TBMDS.

Chapter 3. Methodology Under MOSAIC Approach

The MOSAIC management approach was used to analyze a TBMDS with two assessments: a discrete event simulation and MAAP. The discrete event simulation analysis delves into the physical architecture nuances and the MAAP assessment incorporates the discrete event simulation analysis with all the other factors to address the system risks and opportunities at a consolidated perspective.

3.1. Discrete Event Simulation

The purpose of the discrete-event simulation analysis was two-fold: 1) to prioritize improvement areas of a TBMDS by looking at the system components to determine which area(s) of improvement have the biggest impact on the mission and 2) to better understand how the system architecture nuances influence the mission assurance of the TBMDS. The protocol process followed below is limited to the first purpose and is not to be confused with the overall TBMDS mission assurance of the paper.

3.1.1. Step 1: Problem Formulation

For a distributed system of systems like the TBMDS, commanders of the individual system components tend to advocate for improvements in their own area of influence. A TBMDS commander needs to be able to remove the bias of the individual system commanders and assess the performance of the TBMDS in its entirety. The problem addressed by the discrete-event simulation is the TBMDS commander's requirement to maintain or enhance the mission capability of the distributed TBMD system of systems. For this study, the TBMDS capability assessment ends at the launch of the first interceptor/shooter in response to a ballistic missile threat.

3.1.2. Step 2: Setting of Objective and Overall Project Plan

The objective of the discrete-event simulation consists of identifying and prioritizing the components of the TBMDS that impact mission success the most as discussed in Chapter 1. The overall discrete-event simulation plan is to run a Monte Carlo simulation of the model developed in Arena to complete the objective.

3.1.3. Step 3: Model Conceptualization

The first conceptual model was portrayed in Chapter 2, Figure 1 and its follow-on description. Then the operational sequence model from the MAAP assessment discussed in section 3.2. and shown in Figure 11 provided a more accurate conceptual model with sequence information for the current TBMDS being studied.

3.1.4 Step 4: Data Collection

At a high level of abstraction, the only data required to model the TBMDS is the availability/reliability for each component. In general, the best source for this data is their respective historical maintenance database. The Mean Time to Repair (MTTR) and Mean Time Between Failures (MTBF) gathered from the databases provide the foundation for calculating the component's availability/reliability. Availability/reliability determined by this method calculates the unavailability as the MTTR divided by the MTBF and thus the system availability/reliability as one minus the unavailability (Scheer and Moxley, 2005).

The Army consolidates this information for their radars with the Army Maintenance Database. However, EUCOM's AN/TPY-2 radar is currently contractor maintained and therefore the historical data was not available. Thus, MTTR and MTBF were obtained from the Army Maintenance Database for Support Equipment for a similar radar system with similar complexity. The SMEs assumed that systems of comparable complexity and exposure will have similar failure rates. For the communication links, this process was already conducted in a digital communication reliability paper for fiber optic I/O (Scheer and Moxley, 2005). Therefore the availability/reliability data for the communication links was pulled directly from the paper. The interceptor and C2 facility availability data was provided by subject matter experts (SME).

3.1.5. Step 5: Model Translation

The Arena simulation software was used to help demonstrate, predict, and measure system strategies for effective and efficient performance. The Arena simulation software uses representative process or logic modules joined by connector lines to show how entities flow through the simulated system in a prescribed way. The uniform distribution and Arena's default stream 10 random number generator sequence was used in the create module, called Sensor in Figure 7, to simulate arrival of theater ballistic events. In addition, the following assumptions were made:

- Only 1 event enters the system at a time
- Events proceed through the system until the component architecture fails; the model does not take into account any early termination instances other than component failure since such circumstances would not be useful for reliability analysis of this problem
- Reliability and availability were rolled into one percentage for each component since events proceed through the system so quickly and infrequently in reality
- The uniform (0, 1) distribution may not be the appropriate arrival distribution; however reliability is independent of the arrival distribution

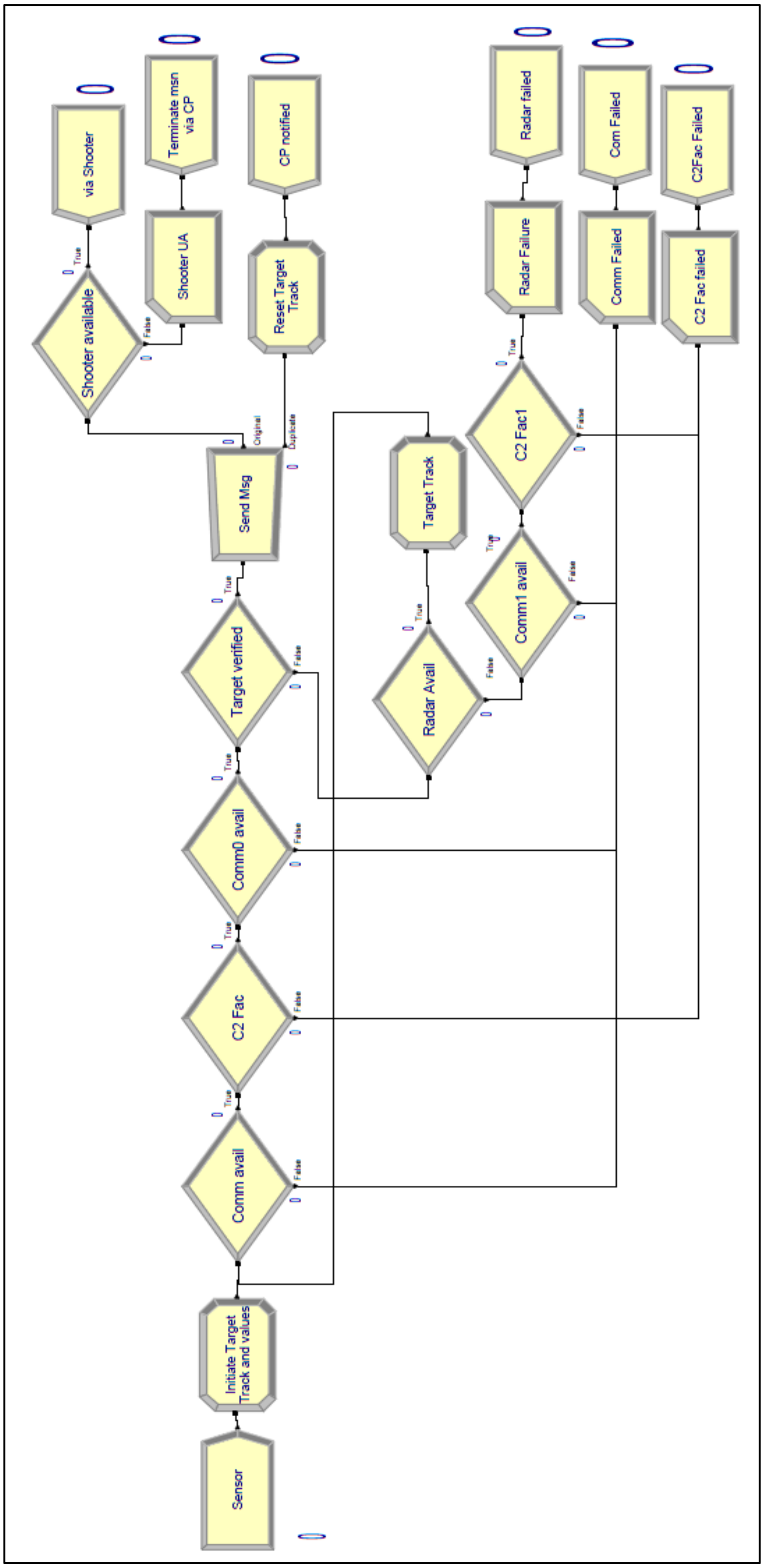

Figure 7. TBMDS Model

Figure 7 depicts the Arena model of the system from the identification of TBM launch by a remote sensor to interceptor/shooter launch.

3.1.6. Step 6: Verification

A number of procedures were used to verify that the conceptual model was correctly translated into a simulation model. First, the number of entities created in the model was compared to the number coming out of the system to ensure they were equal. This confirms that no entities were being stranded anywhere in the model. The next step was to ensure the model addresses the question posed so entities were animated and watched as they flowed through the model to ensure they ran as intended and were consistent with the conceptual model. Finally, the data was checked against mathematic reliability computations which showed the discrete simulation model to be accurately depicting the system.

3.1.7. Step 7: Validation

Next, the model was validated to ensure that the right model was built. The first step was to recognize the model's limitations and purpose. The purpose of the model was to prioritize the components used to complete the mission for the launch of the first interceptor/shooter and therefore the system was only modeled up unto that point. Since a field test was out of the question, the results were assessed and no significant differences were noted between the model and reality.

3.1.8. Step 8: Experimental Design

Following the Design of Experiment process, the objective was set to prioritize the top components that impacted mission success the most. Mission success in this model was defined as the launch of the interceptor/shooter. Normal distributions were developed around the appropriate levels for all the components to set the range of factors to be analyzed. The normal distributions used for each component are shown in Table 1. A small sample size was analyzed at first, and then the appropriate number of production events was established at 100,000 events.

Component	Distribution Parameters (%)
Radar	Norm(97.9, 1)
Comm	Norm(99.9, .3)
C2 Fac	Norm(99, 1)
Shooter	Norm(50, 10)

Table 1. Component Reliability Distribution

3.1.9. Step 9: Production Runs and Analysis

Analysis of the productions runs used the paired t-test confidence interval (CI) with error, α, equal to 0.01 to rank each scenario with results discussed in Chapter 4. A paired t-test looks at paired sets of measured values and determines whether they differ from each other in a significant way. A graphical representation of the t-test can depict one of the three possible results as shown in Figure 8 below.

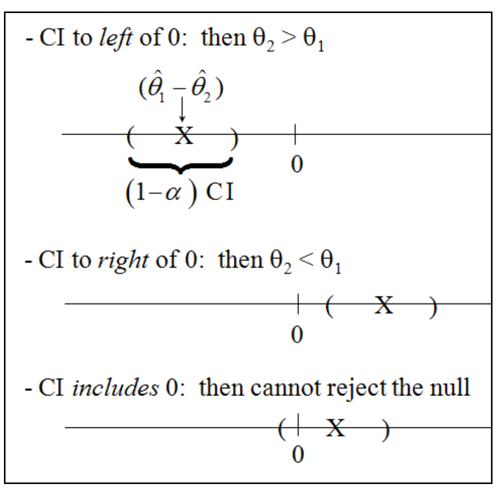

Figure 8. Graphical Representation of paired t-test (Johnson, 2011)

3.2. MAAP

With the methodology for the simulation part of the study complete, the remaining section of this chapter describes the specifics for the TBMDS MAAP assessment.

Since this is a feasibility study, Phase 1, Preparing for the Assessment, and Phase 3, Post Assessment Activities, of the MAAP were unnecessary and therefore not included. Additionally, at a high level of abstraction for the MAAP assessment, the mission does not lend itself to be broken down to only consider launch of the interceptor and therefore for the MAAP assessment the shooter tracking and interception was also taken into consideration to assess mission of the entire TBMDS. This required the following assumptions to be made for the MAAP assessment:

- A discrete event simulation of the entire TBMDS would have similar results to the simulation performed in this paper with the additional reliability of interception for illustrative purposes being 50% (Peña, 1998)
- Lower level key objectives, activities, work products, etc (not in the scope of this paper) support the roll-up of the top level assessment

Following the MAAP activities described in Chapter 2 Literature Review, the operational model was developed using the conceptual model from Figure 1. Four key objectives were established for the TBMDS: 1) negate effectiveness of TBM, 2) negate likelihood of TBM, 3) protect/defend forces/population centers, and 4) strengthening US security relationships with allies (Gompert et. al., 1999; Wilkening, 1999; SECDEF, 1995). Specifically the *negate effectiveness* key objective was understood to include not only the personnel aspect of Key Objective 3 but also the effect of TBM to property, possessions and livelihood. In addition, Key Objective 2 was understood to address the deterrence aspect of the TBMDS. The following key activities were derived from the researcher’s analysis of the operational model to support the key objectives: warn coalition partner, order response to TBM, track targets, communicate target tracks, identify hostile threats to the theater, locate hostile TBM and launch interceptor. For the TBMDS, the work products and key activities were synonymous and therefore a distinction between the two was not used for this assessment. At this high level of abstraction, all the key objectives and activities were able to be aligned with higher headquarters’ mission, the Chairman of the Joint Chiefs of Staff Universal Joint Task List (CJCS, 2002), and therefore were candidates for further mission assurance analysis. The analysis presented here is offered primarily to demonstrate how the MAAP process could be used for TBMDS mission assurance modeling; a more rigorous analysis with appropriate SMEs would provide more useful results. For each key objective, basic success profiles were built by assessing the lowest level of success tolerable and setting that as the success threshold. For Key Objectives 1 and 3, their success thresholds were set to excellent as the loss of any life/livelihood are generally unacceptable from the US perspective. Key Objectives 2 and 4 were set to high since success in these areas are highly sought after but have a lower pain threshold and therefore a lower success tolerance threshold. To assess each key objective’s current potential for success, analysis incorporated not only the full TBMDS discrete event simulation analysis and the operational model which essentially represent similar TBMDS information but other measures are that supported the key objective. For Key Objective 1, this included hardening capabilities and service/support redundancies. For Key Objective 2, this included political/economic actions. For Key Objective 3, this included distance variability from interceptor assets and hardening capabilities. For Key Objective 4, this included memorandum of agreements and conducted exercises. The actual assessment of the top level key objectives' current potential for success is notional without the underlying roll-up support but with the assumed roll-up support, it can be representative.

Next, the success profiles with uncertainty ranges were created by adding a best-case and worst-case potential for success to the basic success profile. All the same aspects analyzed for the basic success profiles of each key objective were reassessed for their best-case and worst-case scenarios. Finally the expanded success profiles were created for each key objective by adding the event sensitivity analysis to the success profiles with uncertainty ranges. In keeping with the intent of this study to determine the feasibleness of the MAAP assessment, only one event was analyzed for all four key objectives, loss of communications. Once again after a loss of communications, all the same aspects analyzed for the basic success profile were assessed and brought the potential for success of Key Objectives 1, 2, and 4 to low and for Key Objective 3 to minimal. The results and analysis of the MAAP assessment is the next step in the process and leads us into Chapter 4 Results and Analysis.

Chapter 4. Results and Analysis

Though the discrete event simulation and MAAP assessments have essentially been discussed separately, the two assessments were interwoven and supported each other. For example, results from one assessment method were used to support the other method, and vice versa. However, to simplify the discussion, the discrete event simulation results and analysis will be discussed first, followed by the analysis for MAAP's expanded success profiles and finally the key findings of the combination of the two analyses will be reviewed.

4.1. Discrete Event Simulation Results

At the level of analysis conducted by this study, the discrete event simulation model resulted in a *series system*. At first glance, this appeared to be a wonderfully simplifying conclusion since reliability importance theory shows "that the least reliable component in a series system has the biggest effect on the system reliability" (ReliaSoft Corporation, 2007). Therefore, improvement to the component with the least reliability will always have the biggest impact on the mission from a system reliability perspective. However, a TBMDS while still a series system uses some components more often than others and therefore a discrete event simulation was able to resolve the component utilization discrepancy not as easily computed by reliability importance theory. Using the reliability distributions in Table 1, the executed discrete event simulation of the base system is shown in Figure 9. Figure 9 shows the results of one production run of the Base system annotated with the count of entities for each path. Mission success in terms of the launch of an interceptor/shooter was 47586 beside the via shooter module for this run.

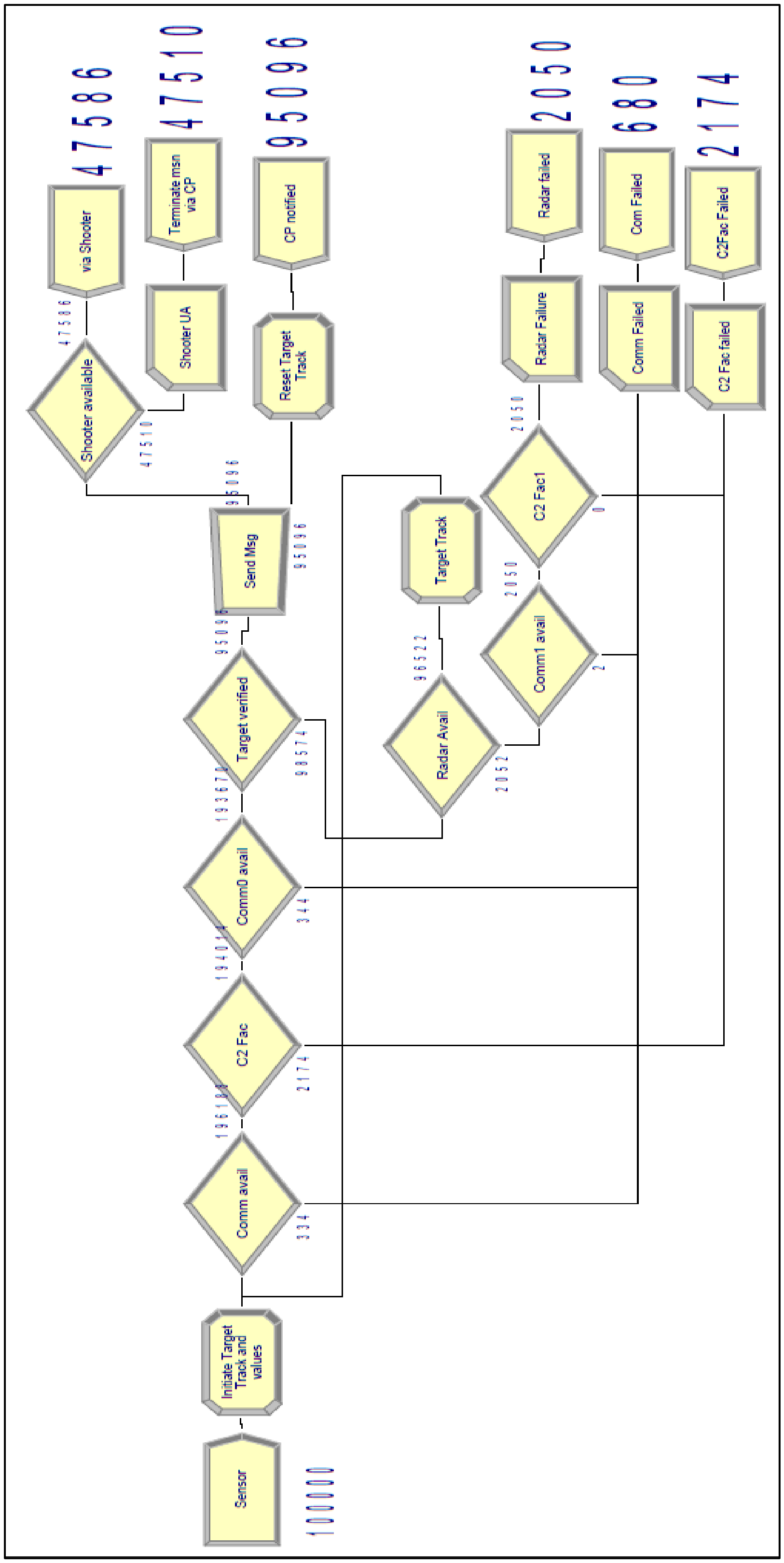

Figure 9. TBMDS Model Executed

In order to understand the significance of component improvements, three alternatives to the base system were initially analyzed. Alternative 1 increased the shooter availability/reliability from a mean of 50 to a normal distribution with a mean of 75 and variance of 10 from Table 1. Alternative 2 increased the C2 Facility availability/reliability to a normal distribution with a mean of 99.9. Alternative 3 increased the Radar availability/reliability to a normal distribution with a mean of 99. For each of these alternatives the discrete event simulation model in Figure 9 was run again. Figure 10 shows the resulting paired t-test comparison of the combination of the Base system, denoted as Base, and the three alternatives, designated by their number, taken in pairs.

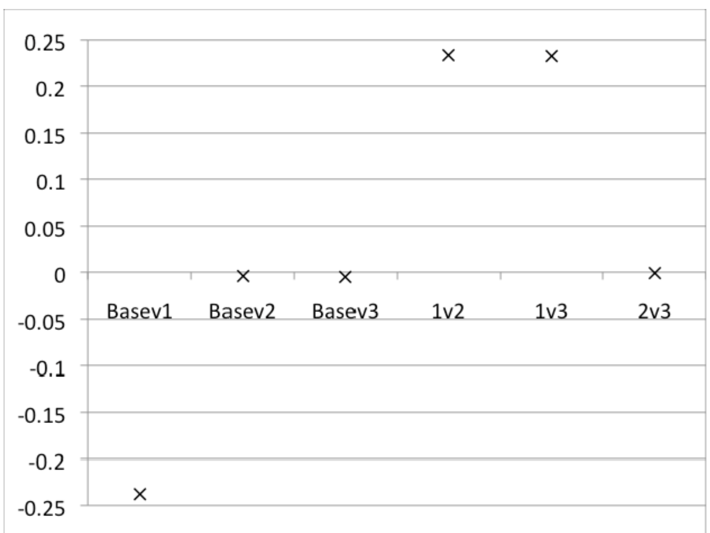

Figure 10. Mission Success Paired t-test

Figure 10 shows a statistically significant improvement for Alternative 1 indicating that an improvement in the shooter availability is the best alternative system. To bring fidelity to the remaining component improvement alternatives, a second paired t-test was conducted with mission success modified to the successful notification of the coalition partner. The Alternatives remained the same except Alternative 1 was modified to an improvement of the communication component with a normal distribution mean of 99.99. Figure 11 shows the resulting graphical depiction. Though all the alternatives have statistically significant improvements over the base system, the margin of improvement is relatively small compared to the system reliability improvement to be gained by the shooter component.

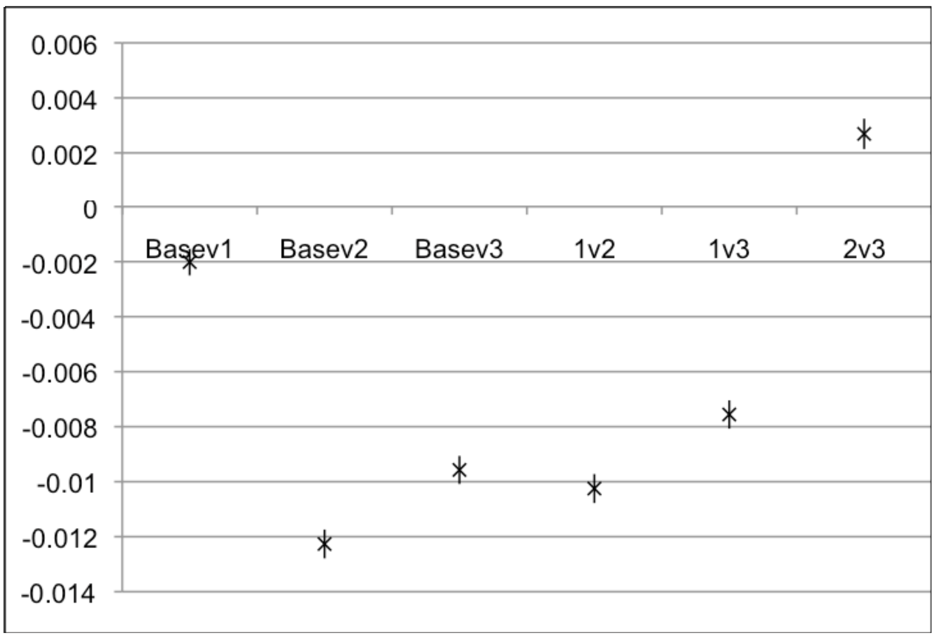

Figure 11. CP notification Paired t-test

Examining the paired t-test results in Figures 10-11, resulted in the component prioritization listed in Table 2.

Component	Improvement Mission Impact
Shooter	**Most**
C2 Fac	
Radar	
Comm	**Least**

Table 2. Component Prioritization

Table 2 does not take into account any cost benefit analysis, but from a system reliability perspective it prioritizes the component improvements that have the biggest impact on the mission.

4.2. MAAP Success Profiles

As experience has taught us, system reliability alone does not indicate mission assurance. Though the component/system reliability does play a part and therefore was incorporated into the MAAP assessment[3]. After reviewing the conceptual model in Figure 1 and the figure's description, the detailed operational model in Figure 12 was developed to ground the remaining MAAP analysis.

Then the key objectives and activities were established and aligned with the Chairman of the Joint Chiefs of Staff Universal Joint Task List (CJCS, 2002). Key objectives that would not have aligned with direction from higher headquarters would have been an indicator of potential improvement areas or candidates for re-alignment. However, the four key objectives established for the TBMDS, readily aligned to the Chairman of the Joint Chiefs of Staff Universal Joint Task List (CJCS, 2002) as shown in Figure 13.

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[3] For this feasibility study, the author instead of a team of experts completed the MAAP assessment.

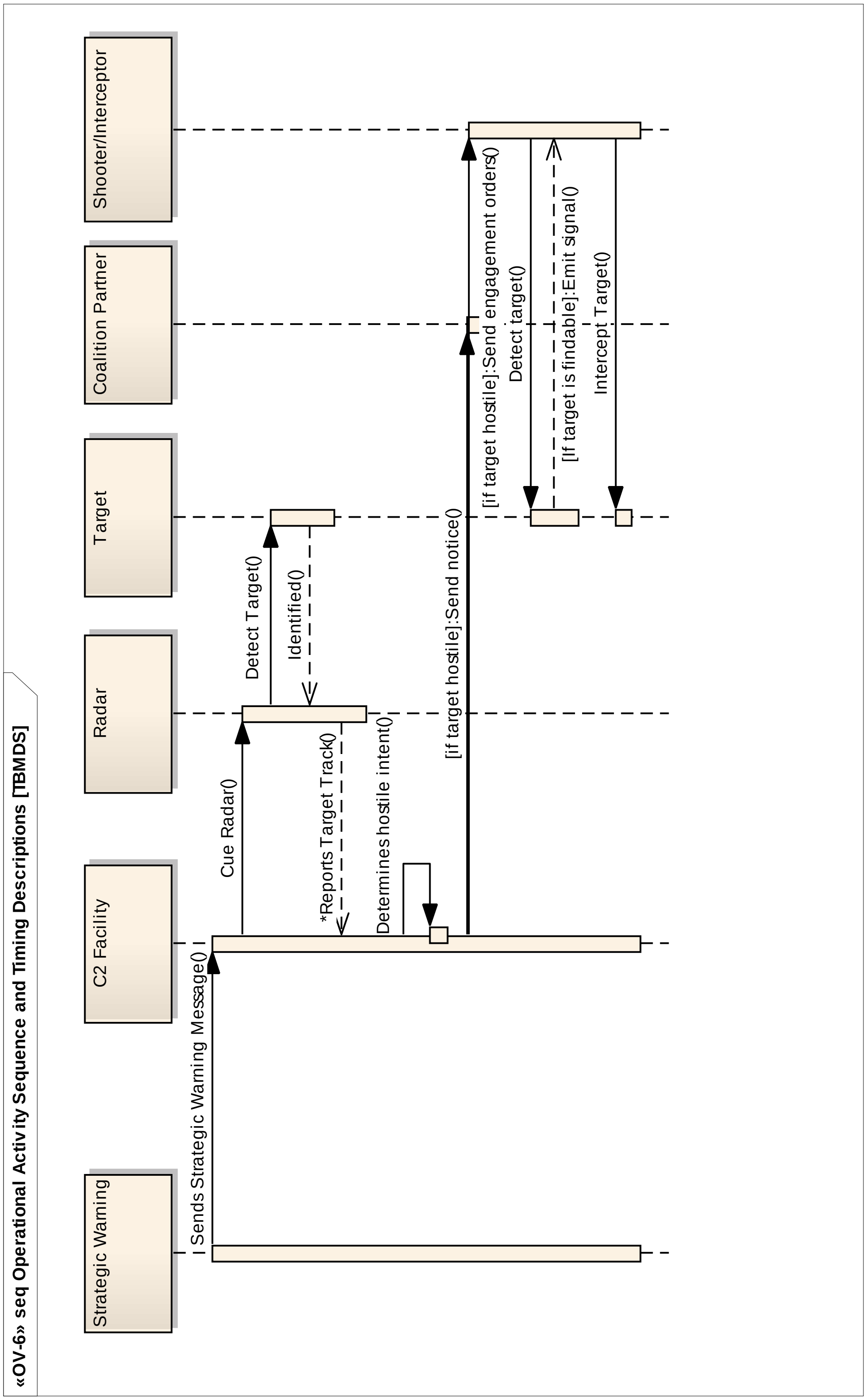

Figure 12. TBMDS Operational Sequence Model

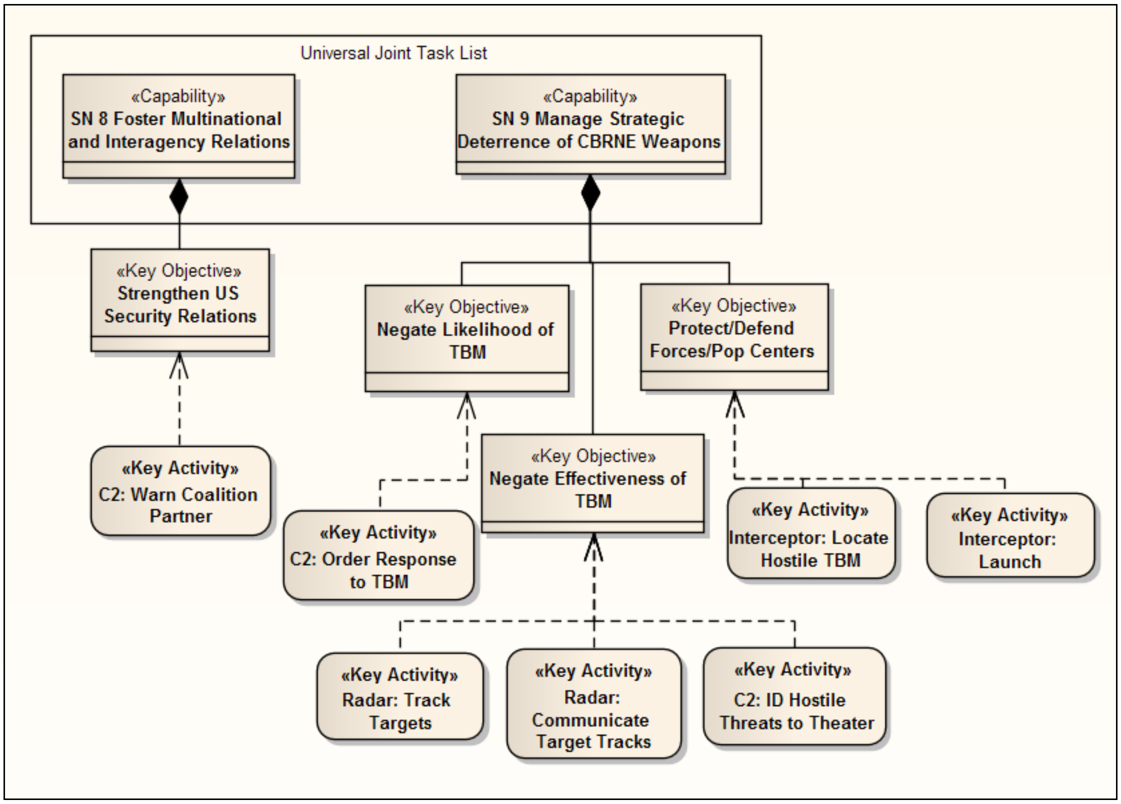

Figure 13. Key Objective and Activities

Armed with the operational model from Figure 12 and the establishment of the key objectives and activities in Figure 13, the analysis of the TBMDS's potential for mission success evolved from basic success profiles through the steps described in section 2.3.1 and explained in section 3.2 to the expanded success profiles shown in Figures 14-17. As shown, Key Objectives 1, 2 & 3 of the TBMDS have gaps between the current potential for success and the desired success thresholds. However, Key Objective 2 has an uncertainty range that has the potential to eliminate its gap. Unfortunately, all four key objectives are still sensitive to event occurrences that degrade their potential for success to low or minimal levels. Therefore the analyzed TBMDS has many areas of improvement to reach the desired success threshold.

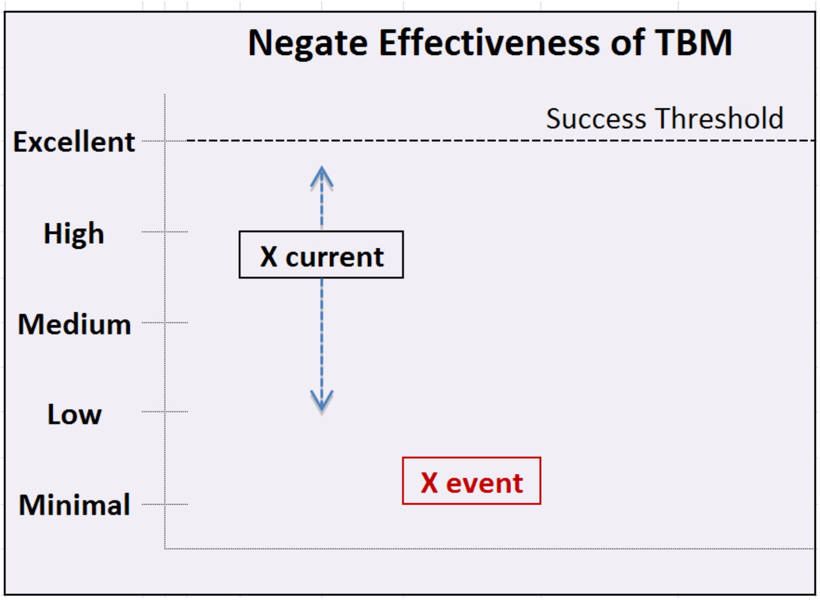

Figure 14. Key Objective 1

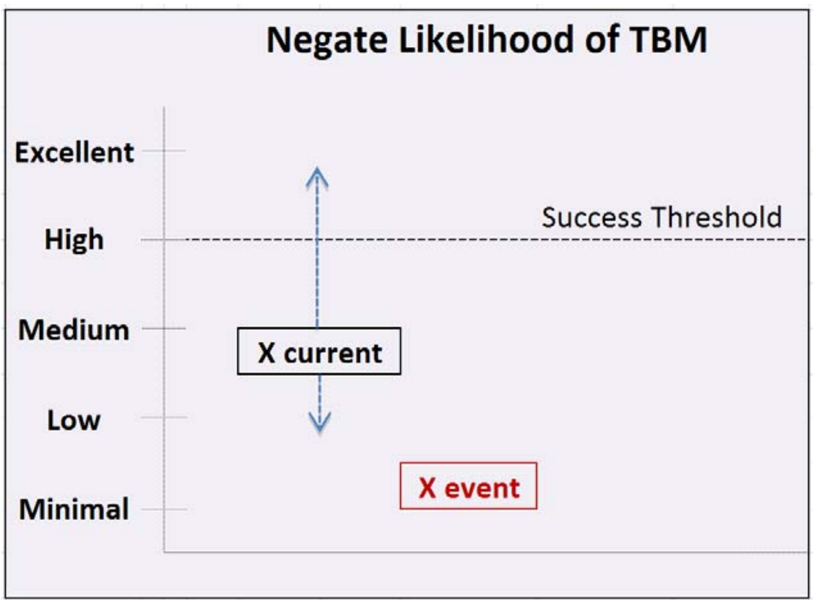

Figure 15. Key Objective 2

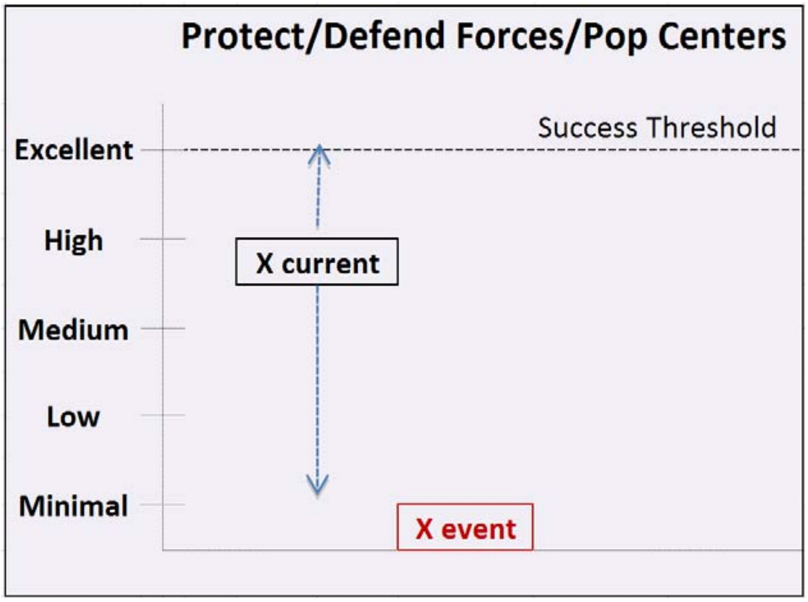

Figure 16. Key Objective 3

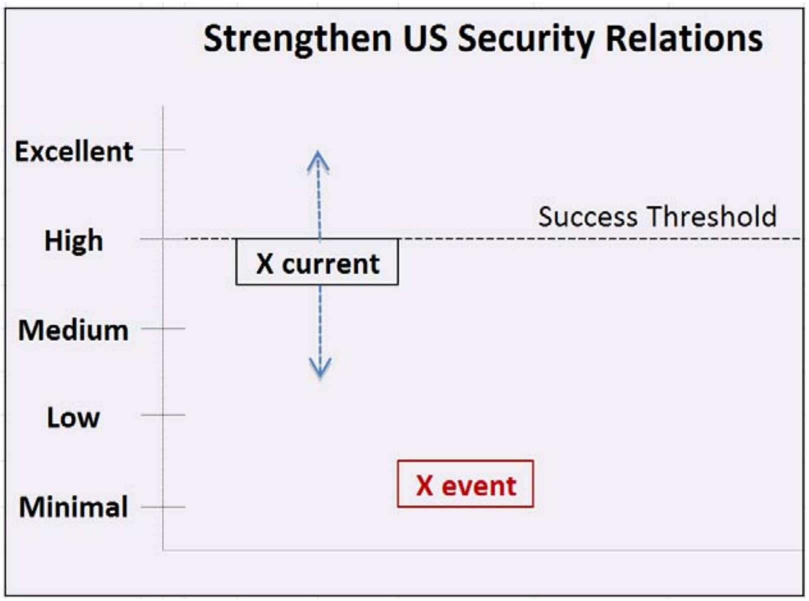

Figure 17. Key Objective 4

4.3. Summary of Analysis Results

The discrete event simulation analysis provided the component improvement prioritization of shooter/inceptor, C2 Facility, Radar and Communications. The MAAP identified gaps between the current potential for success and the desired success thresholds for three of the four key objectives. Both analyses indicate that the TBMDS has warranted improvements to be made. The MOSAIC management paradigm from Figure 2 would use the details provided by the discrete event simulation and MAAP assessments to develop an action plan for improving the TBMDS's potential for success in this case. Then commanders would follow though by implementing, tracking and controlling the planned improvements.

Chapter 5. Discussion and Conclusions

With the financial constraints faced by commanders today and the oversight technology immediately provides when mission success is in question, commanders need the efficient mission assurance management approach MOSAIC can provide. From prioritizing and justifying funding requests to operational mission assurance, MOSAIC has the modularity to handle the range of complex systems. The TBMDS mission assurance approach captured in this research represents a methodology field commanders can utilize by the very nature of having a command, the mission, and furthermore, the alignment of their mission to the next higher level of command's mission described in this paper as the enterprise-wise alignment of key objectives. Additionally, the MAAP assessment has the comprehensive analysis required to capture the complex environmental interactions inherently found in a TBMDS.

This research focused mainly on the assessment activity within MOSAIC to show an alternative to the traditional risk management approach. By incorporating the assessments of SEI MAAP and a standard discrete event simulation, not only were synergies recognized within the processes but also a balance between subjectivity and objectivity was achieved. The assessment piece provides a solid foundation for the follow-on activities of planning, implementing, tracking and controlling necessary to achieve/maintain the desired outcome. The follow-on activities are generally better understood and incorporated and therefore were included more for completeness of the MOSAIC approach than as additional areas of research.

From a high level of abstraction, MOSAIC's discrete event simulation and MAAP assessments indicate that the TBMDS has potential improvement areas before mission assurance is established. However, further research in this area could use a specific system's actual component reliabilities and delve into the enterprise-wide alignment of key objectives down to the operational processes which include all tasks, policies, procedures, organizations, people, technologies, tools, data, inputs, and outputs needed to achieve the specified mission using an team of experts for an in depth MAAP assessment. Additionally, this study only took into consideration the components of the US TBMDS system from a EUCOM perspective. As agreements are put into place and theaters begin to rely on the assets of multiple nations, a combined organization like NATO, could use the assurance a theater-wide TBMDS MOSAIC approach would provide.

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Vita

Major Susan R. Olsen graduated from Ravenswood High School, WV in 1994. She completed a Bachelor of Science degree in General Engineering at the United States Air Force Academy in May 1998. Upon graduation, she was commissioned a second lieutenant in the Air Force. Major Olsen's first assignment was to the Oklahoma City Air Logistic Center at Tinker AFB, OK. There, she served as an F-16 Structural Engineer for the Technology/Information Directorate and then a B-52 Project Engineer for the System Program Office. During that time she also performed as an Air Battle Damage Repair Engineer. Next, she was assigned to Hill AFB, UT, where she was the Chief of the Ground Operations Flight for the 388th Range Squadron, the 388th Fighter Wing Executive Officer, and the Flight Commander for Range Support Logistics. Following her tour at Hill, Major Olsen was assigned to Osan AB, ROK, where she was the Director of Communications and Information for the Air Component Command. Major Olsen's next assignment took her to Brooks City-Base, TX where she served as the Aircrew LASER Eye Protection Program Manager culminating as the Chief of Aircrew Performance Acquisitions for the 648th Aeronautical Systems Squadron. She then moved over to Randolph AFB, TX to work at the Air Force Personnel Center as the Chief of Engineering Officer Assignments before taking over as Deputy Chief of Acquisition Officer Assignments. Upon graduation, Major Olsen will work acquisition career field issues for SAF/AQH in the Pentagon.

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14. ABSTRACT

In today's budget-constrained environment with aging equipment and rapid technology turnover, the commander's requirement to prioritize and justify funding requests has essentially become an exercise in mission assurance. This study addresses the TBMDS mission assurance problem generated from the complexity of the political, organizational and physical/architectural environments. The Mission-Oriented Success Analysis and Improvement Criteria (MOSAIC) management approach provides commanders a framework for mission assurance of TBMDS. This study specifically incorporates a discrete event simulation analysis and the Mission Assurance Analysis Protocol (MAAP) to identify the most effective improvement areas under the MOSAIC approach. At a high level of abstraction, analysis from a discrete event simulation of the TBMDS prioritized the component reliability from the most to least impactful as shooter/interceptor, C2 facility, Radar and Communication. The MAAP expanded success profiles simultaneously address multiple environmental factors, including reliability, for each key objective needed for the mission. At an equally high level of abstraction, these profiles identified that one key objective of the TBMDS can be achieved successfully and three key objectives had significant mission assurance gaps. With improvement areas and mission assurance gaps identified, commanders are equipped with the required information for funding requests and confidence in the success of their mission.

15. SUBJECT TERMS

Mission Assurance, Theater Ballistic Missile Defense System, discrete event simulation

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					Michael R. Grimalia., PhD, ENV
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